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AGRICULTURAL MEMORANDUM NO 583

An annotated bibliography on the effects of mulching on plant climate, with some comments on consequent yields.

Parts VI and VII - Effects on growth and yield of plants

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Previous parts of this bibliography were issued as Agricultural Memoranda Nos 392, 423, 523, 548 and 554.

6.1 NO SPECIFIC CROP

No references.

6.2 TEMPERATE TREE FRUITS

Organic mulches

Mulching apple trees with hay, particularly when enriched with nitrogen, is shown by Boynton (1) to increase total yields, tree girth and fruit size but he also found that the mulches increased pre-harvest drop and decreased the red colour and firmness of the fruit. Harley (2) claims that any hay crop containing 2% or more nitrogen on a dry weight basis was markedly superior to straw when used as a mulch. Toenjes (6) found that mulches of lucerne, mowed once or twice a year, retarded growth and fruit production of Bartlett pear trees in USA for the first 12 years after establishment. From then on the trees made greater trunk circumference increase, produced heavier annual crops and larger fruit than trees on clean culture plots. In Germany, however, Will (19) reports that while grass mulching delayed flowering by 3-5 days in comparison with clean cultivation it gave the better fruit colour.

An oat straw mulch applied to pear, apple and peach trees in Australia is shown by Sell (3) to give a general yield increase after the first year and to double yields after 6 years. In the sixth year, after 8 weeks of dry weather, Gravenstein trees had greener foliage and larger, better coloured fruits than those on unmulched plots. Hughan (4) also in Australia, records that the average canning yield of peaches during 6 years from straw mulched plots was 27 tonnes/ha against only 19 tonnes/ha from plots using the standard local practice of summer-weeds and winter weeds. The respective costs were £226 and £63 per hectare.

Studies in Holland by Butijn (8) over 17 years lead to his conclusion that the most favourable conditions for the uptake of nutrients and water occurred with straw mulch plots from which the highest net income was obtained. Engel (13) & (14) shows that German apple yields were higher with a straw mulch or a mustard cover crop than with clean cultivation. The higher yields were due to increased fruit size as well as more fruits per tree. The straw mulch significantly increased flower bud formation and also induced earlier flowers which was accompanied by a greater danger of frost damage.

Fisher (15) reports from America that apple yields were closely correlated with tree size, except that under a heavy straw mulch, yields lagged behind growth rate after 12 years. White (25) however, claims in England that straw mulching produced the most vigorous trees.

Mulches of sawdust were used by Nott (5) who shows that after 2 years there was no significant difference between the sawdust and clean cultivation in respect of annual growth or fruit yield on 40 year old Jonathan trees. Goss (16) however, claims that sawdust markedly improved tree vigour.

Comparisons of the effects using mulches of different materials were carried out by Latimer (9) who reports that over a 12 year period, McIntosh trees mulched with hay produced 50% more fruit than trees grown in grass without additional mulch or with pine sawdust which produced poor results. Soczek (11) in Poland however, shows that there was no significant difference between mulching cherry trees with sawdust, peat or straw, all of which depressed the growth of trees and roots, and increased frost damage. Klossowski (17), also in Poland, found that yields over 8 years were much the same under a cover crop or permanent grass but a straw mulch increased yields 3-4 years after application; a sawdust mulch gave the poorest results. In India, Srivastava (21) also found no differencesduring the first 5 years of a trial using mulches of pine needles or oak leaves compared with no mulch. However as time progressed, better growth and yields were observed on mulched trees, especially using oak leaves which also greatly improved fruit colour.

A trial in Germany with four different apple varieties is shown by Hilkenbaumer (22) to indicate that clean cultivation gave better young shoot growth and larger crown volumes than either grass or straw mulches. After 3 years there was also a tendency towards higher yields on the clean cultivated plots.

Simons (24) compared mulches of straw, whole or ground corn-cobs with no mulch and found that Golden Delicious trees on the irrigated no mulch plots made similar growth to those on the straw covered, non-irrigated plots.

A 12 year trial is described by Greenham (26). Grassing down caused a severe check to apple trees and the competitive effects lasted for the first 4-6 years when cropping was also adversely affected. Straw mulch stimulated the growth of the trees but during the first 6 years, cropping was relatively light but with a lighter system of pruning these effects were reversed. Throughout the trial, mulching noticeably increased the pre-harvest fruit drop.

Non-organic mulches

Miller (20) shows that black plastic film used under 2 year old apple trees greatly increased shoot elongation in the young trees.

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6.3 TEMPERATE HORTICULTURE AND SOFT FRUIT, VEGETABLES AND FLOWERS

Organic mulches

Strawberries:

Experiments in USA by Roberts (7) show that a 10 cm mulch of fir sawdust gave higher yields of strawberries than either fir or alder sawdust incorporated into the soil or than clean cultivation. Oele (12) compared caraway and barley straw with bare soil in Holland. Yields were similar at first picking, but by the third picking, plots covered with caraway straw were cropping the best. Final yield from the caraway straw plot showed an increase of 14% over the bare plot and the number of first quality fruit was also increased. Barley straw, meanwhile, reduced the final yield by 7% but also gave more first quality fruit than did bare soil. Schulz (53) studied the effects of a mulch of leaves (with some grass and wood shavings) for more than 5 years. The initial mulch was 15 cm thick and a 5 cm layer was added annually. He found that strawberries did not benefit from the mulch.

Bush fruit and vines:

A single application of sawdust 7.5 cm thick is shown by Webster (5) in Canada, to increase loganberry yields by 3.5 tonnes/ha/year for a 7 year period. Roberts (17) however found in USA that raspberry yields were not improved by sawdust mulching. Hill (24) meanwhile reports that mulching raspberries was superior to soil cultivation, producing better growth and yields and also larger berries. Clay (73) presents a report on a 4 year study in England using straw mulches on raspberries. Consistently higher fruit yields and marked suppression of sucker growth were given by the mulched treatments.

From whole bush excavations of blackcurrants and root sampling at selected depths, Coker (8) concludes that the presence of a straw mulch applied at 20 tonnes/ha in three consecutive winters increased the activity of shallow roots and decreased that of deep roots as compared with clean cultivation. Schulz (53) found that only in weak growing varieties of gooseberries was a mulch of leaves effective on growth and yield.

Beattie (3 & 20) shows that straw mulching increased the yields of vines in the USA when the May-September rainfall was < 438 mm but decreased them when the rainfall was > 505 mm. The mulch also resulted in the production of fruit containing lower soluble solids and higher acid contents than did cultivation. He considers that the use of a permanent mulch system of management for Concord grapes is economically sound and possesses certain advantages not obtainable under the conventional cultivation plus cover crop soil management system. Hénin (38) reports that a mulch of straw at 10 tonnes/ha on shallow, sandy and poor structured soils was not effective but that straw applied at half that rate and incorporated when partly decomposed, progressively improved vine root growth and fruit yields in France.

Vegetables:

Fekete (1 & 6) shows that yields of sugar beet in Hungary were increased by 9% using a peat mulch, by 19% using manure and by 35% using a straw mulch. Similar results are reported from Germany by Rauhe and Lehne (26 & 30) using a mulch of straw or potato tops at 10 tonnes/ha on potatoes and sugar beet.

Massey (10) compared sawdust mulching with clean cultivation on a number of vegetable crops. Mulching increased yields by 332% with cucumbers, 62% with tomatoes, 33% with lettuce and 30% with snap beans.

In a 2 year trial Lent (9) used a 7.5 cm layer of poultry manure applied at 75 tonnes/ha, with and without a 2.5 cm covering layer of sawdust with tomato plants set directly through the mulch. Yields in the first year were satisfactory and during the second year they were significantly higher from the mulched plots than from the control, there being no difference with the additional sawdust layer. White (19) also recorded higher yields of tomatoes and lima beans when using a mulch of pine sawdust at about 50 tonnes/ha.

Straw applied at 8 tonnes/ha as a mulch to field grown cucumbers in Bulgaria is shown by Surlekov (68) to increase yields by 16%. However, Nicolaisen (92) claims that straw mulching retarded germination and lowered yields of spinach but gave higher yields of cauliflower after an extremely cold growing period in Germany.

Flowers:

Čikalov (35) reports a 6 year trial in Russia, in which a straw mulch at the rate of 5-6 tonnes/ha (12-15 cm deep) was applied in the rows of oil-bearing roses. Root growth was promoted, the number of flowers was increased and essential oil yields were improved by 71%. Overall costs of flower production were reduced by 25%. Carpenter (4) used mulches of ground corncobs on greenhouse roses, either 5 or 10 cm thick. There was a substantial increase in the number of flowers with both treatments, the best yield resulting from the 10 cm mulch.

With azaleas, Roberts (17) claims that a sawdust mulch was superior to one of straw or oak leaves while Creech (21) used a 10 cm hay mulch to greatly improve their growth in the nursery, but found that retention of the mulch throughout the winter resulted in severe frost damage.

Dutch work with freesias is reported by Kragtwijk (2) who shows that soil coverings of reeds or chaff had a good effect on the growth and corm weight of the variety Buttercup.

Non-organic mulches

Strawberries:

The effect of black plastic mulches on the yields of strawberries has been examined by many writers. Brooks (11) claims significantly increased yields in the USA, advanced ripening by 6 days and also prevention of soil rot on the fruit. Germing (22) in Holland found that yield increases had disappeared by the second year while Bargioni (34) presents economic comparisons using black plastic mulches in Italy. First year results were about equal while in the following year when it was hot and dry, the mulch depressed yields. However, in the third year which was cool and rainy, the mulched plants produced more, earlier and healthier fruit than the unmulched plots which were heavily infected by Botrytis.

Lemaitre (40) in France, claims more roots, buds and runners using black film (70 cm wide), earlier flowering (3-6 days) and harvesting (2-3 days) and yields were increased by an average of 20%, and Linden (50) reports similarly from Belgium. Cox (47) in Australia quotes yield increases of up to 70% but Thorsrud (69) found that yields in Norway were not significantly higher although ripening was about 4-5 days earlier. Van Nerum (81) in Holland however, obtained increased flowering by up to 28% and yields by up to 38% compared with those of plants grown in bare soil, depending upon the variety.

Thompson (28) obtained yield increases on strawberries using an opaque plastic mulch, while Voth (33 & 46) found that in California a clear polythene mulch applied in November or December increased fruit yields by an average of 70% and average fruit size by 4.4% in comparison with late mulching in mid-February. Runner production however, was 29% greater from the late mulched plants. Voth (18) further found that yield increases from clear polythene mulches were significantly higher and earlier than from other types of plastic mulch or without a soil covering.

In France however, Bry (84) found that mulching strawberries with clear polythene depressed yields compared with the control while grey or black polythene, either perforated or not, raised yields appreciably but there were no significant differences in yield or earliness between the four types.

Bush fruit and vines:

Porter (42) reports from New Zealand, that mulching with black polythene sheeting resulted in greatly increased growth of newly planted blackcurrant and boysenberry plants, slight growth increases of gooseberry plants but made little difference in the results for raspberry plant growth. Black polythene mulch was applied to Concord vines in Canada by Moore (52). Growth was greatly increased during their first summer and this effect persisted into the third year, so that the mulched vines fruited a year earlier than unmulched vines. The mulch also increased the survival and subsequent growth of Concord cuttings rooted in their permanent position.

Vegetables:

The merits of using clear polythene sheeting as a mulch have been listed by the following authors; Mareček (32) in Czechoslovakia, quotes yield increases of 272% with melons, 157% with cucumbers, 93% with peppers and 64% with tomatoes and claims that ripening was also advanced. Somos (43) in Hungary and Tarakanov (62) in Russia also obtained yield increases over a wide range of vegetables while Cerveau (87) in France enhanced early asparagus yields considerably, raised total yields by 3.3 tonnes/ha and increased earliness by about 8 days.

Darby (48) tested eighteen different formulations of plastic and petroleum emulsions over 2 years and found that they increased plant growth and yields, hastened maturity and prevented wind erosion when used on vegetable seedbeds. Milner (51) used a petroleum resin sprayed in bands along the rows after sowing and obtained yield increases varying from 17 to 67% over a wide range of vegetables. Takatori (54) and Agamalian (71) also in USA used a similar mulch to promote early germination while Jordan (76) gives the results of 3 year trials in England, Trinidad, and Italy with a wide variety of crops most of which showed marked yield increases. Sale (79) again in England, found that a petroleum mulch consistently increased the final number of seedlings, the earliness and also the uniformity of emergence.

Pearson (16) used aluminium foil in the USA in widths varying from 45 to 180 cm during three seasons. The first year was hot and dry and the mulch increased the yields of tomatoes by 165% and cucumbers by 290%. The following year had adequate rainfall and the beneficial results were much smaller. During the third year, rainfall was below average but temperatures were not very high and again there were substantial yield increases from the mulched plots.

Mulching with paper impregnated with bitumen and other chemicals is shown by Muratova (41) to advance germination of onion sets by 3-4 days and to increase yields by 25%.

Outdoor tomatoes have responded well to mulching. Autry-Hall (13) in Australia and Austin (56) in England both used black polythene film and obtained yield increases of 240% and 25-30% respectively. Geraldson (49) in the USA increased the yield by 66% when the plants were unstaked and 20% when stakes were used, due mainly to ground rot being negligible.

Acquier (70) reports that clear and black films did not affect tomato yields, while a grey film increased them by only 6% in France. Hall (88), in a 3 year trial in the USA, found that mulching with black, clear and grey film resulted in larger tomato plants but yields did not reflect plant size.

Plastic mulching of potatoes and other root crops has been examined in many parts of the world. Hensel (39) used black film in USA to increase yields and improve the quality of the tubers. Bajec (83) also used black film in Yugoslavia but found that although yields were slightly reduced the percentage of diseased tubers was reduced from 20% to 13% compared with conventional ridging. Danish work (82) shows that a clear film resulted in better yields than white, black or green sheets but Alpi (72) and Caruso (91) in Italy found that a clear film resulted in lower yields than the bare control plot while black film significantly increased yields.

In USA Knavel (65) recorded much increased yields of sweet-potato using both clear and black films while Miller (77) found that yields were increased only with a white film, black film had little effect and clear film reduced yields. Herje (74) however, forced early potatoes in Norway under a clear film and increased the yield of marketable produce by an average 0.12 tonnes/ha.

Total yields of cucumbers from plants mulched with a clear film under a plastic frame in Russia, is shown by Tarakanov (45) to be 20-30% higher than unmulched plants and also that early pickings of small fruits were 30-110% higher. Similar large increases were obtained by Johnson (75) in USA using a petroleum based wax emulsion mulch at 0.33l/sq.m. Oebker (14) found meanwhile, that a kraft paper mulch containing a fungicide was more effective than black plastic in increasing early and total yields of cucumber.

In France, Acquier (70) used transparent film to increase the weight yield of early melons by 54%, while smoked film increased yields by 62%. In Italy, Baroccio

(63) sprayed petroleum resin along the rows after sowing melon seeds and noted accelerated germination and considerably increased yields. In USA Bryan (85) found that both clear and black mulch increased earliness of watermelons and that the clear mulch was the most economical. Sumeghy (93) used a bitumen mulch 15 cm wide after sowing melon seeds and shows that 62-87% germination took place under the mulch compared with 21-43% for the unmulched control. Other beneficial effects included enhanced early growth of the mulched plants, which were 2-3 times the size of the controls.

Flowers:

Habran (37) used black polythene film in growing chrysanthemums in Belgium. Growth, yield and quality were the same as in the control plots, the benefit being found in the reduced need for hoeing. Meanwhile in Japan, Ono (15) notes that a vinyl film on summer chrysanthemums advanced the date at which flowering started by 5 days and the peak period of flowering by 7-10 days. Elia (58) in Italy, found that a perforated black film resulted in earlier emergence of gladioli, with significantly more and larger flower spikes on longer stems in the first year, and in earlier flowering in the second year which was wetter than the first.

Mixed mulch comparisons

Strawberries:

The early and total yields of strawberries were significantly greater from plastic mulched plots in the USA than from plots mulched with paper or pine straw or not mulched at all, according to Locascio (31). Similar results are reported from France by Lemaitre (59) who, in a comparison between black polythene film and straw, noted that the film advanced flowering by 2-5 days and picking by about 3 days. Shetty (61) in USA presents a thesis and quotes the following yield increases, taking a sawdust mulch as 100%: white film 22%; clear film or clean cultivation 23%; sawdust together with clear film 31% and finally black film 116%. Srivastava (67) in India shows that black polythene mulch encouraged continuous growth of strawberries and retained its superiority over a hay mulch and the control throughout the year; whereas Overcash (78) claims that on a sandy loam soil, plant survival after 2 years in USA was about twice as good with pine straw or sawdust mulches as with clean cultivation or black plastic mulch and further, that the vigour of the surviving plants was better and yields were greater.

Sogo (89) reports from Japan that the growth and yield of grapes were higher with a straw mulch than with a vinyl or sod mulch but that the best root development took place under the vinyl mulch.

Vegetables:

Greig (23) compared several mulches on a tomato crop in USA and found that while both a black plastic mulch in strips about 1 metre wide and a wheat straw mulch 7.5 cm thick applied in May increased yields, the plastic was better by 11%. Chapman (57) however, records that a 5 cm mulch of sugar cane bagasse produced bigger yield increases of tomatoes than a black polythene film.

Woodbury (55) quotes the following average yields of melons per hectare using different mulches: black plastic 22,000, aluminised plastic 20,000, straw 2,750 and with no mulch 7,400 melons. The plastic mulch also advanced peak production by 1-2 weeks. Schales (60 & 80) used several mulching materials and shows that peat moss and straw mulches generally delayed fruit set and reduced plant growth of muskmelons. Plant growth was most rapid, fruit was earliest and yields were highest with plastic mulches. A petroleum mulch increased early fruit set but had less effect on plant growth. Similar results were found during two seasons in India, when Rahman (66) shows that a polythene mulch had a favourable effect on the growth and yield of cauliflower while a straw mulch had an adverse effect.

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6.4 FORESTRY

Organic mulches

Chopped straw mulches 2, 4, 6, 8 and 10 cm deep were used in a Pine nursery in Bulgaria by Dakev (8) who recorded that the 2 and 4 cm mulches gave the best height growth and root collar diameter which decreased with increasing mulch depth, but even the 10 cm mulch gave better results than the unmulched controls. Jobling (14) found in England that mulching with straw 15 or 30 cm deep for at least 60 cm around each Poplar tree stimulated height growth more than mounding, while Ursic (30) reports from USA that spot mulching Loblolly Pine trees to a radius of 23 cm was as effective as blanket applications in increasing first year survival on barren eroded sites, and it also improved height growth. He preferred pine litter to straw as a mulch because it was more resistant to movement by wind and water.

The use of sawdust as a mulch on Pine seedlings in USA is reported by Posey (3) who claims a higher percentage survival at the end of the first growing season. Farnsworth (7) claims a more rapid growth with sawdust and also suggests that a 2 cm mulch was more effective in increasing height growth than mulches 2 or 5 cm deep. Lowry (15) meanwhile shows a 90% increase in survival of conifer on strongly acid, sandy soils using an unsteamed sawdust mulch, but he found that a steam-sterilized sawdust mulch was less effective on sandy soils and even decreased the survival rate when used on areas high in silt and clay. No height differences resulted from these treatments. Rjabinin (26) from Russia,quotes a 20-40% increase in seedling yield using a 2.5 cm sawdust mulch which is shown to be better than a moss mulch.

Champagne (1) claims a 20% better Red Pine survival rate after two growing seasons in USA, using a mulch of wood chips. Growth, colour, condition and needle length were also improved. Forest litter and humus were applied as a mulch 20 cm deep in Latvia by Bušs (12) who shows that it increased the height increment of Scots Pine by 58% against an increment of only 18% when the litter was incorporated into the soil. Similar materials were used in USA to a depth of 5-7 cm, by Sartz (27). The litter increased the height growth of Black Walnut, Red Oak and White Oak by averages of 55, 51 and 40% respectively after 5 years. Differences in the 8th year were 42, 53 and 52% (the site being unsuitable for walnut). The mulched plots (6 x 3 m) also doubled the yield of air-dry thinnings.

Leyton (2 & 5) shows that the application of a heather mulch in England had a marked stimulating effect on the growth of Spruce and Pine, while on Lawson Cypress it more than doubled the height of the trees in 8 years compared with the untreated controls. Similar results are reported by Nedkvitne (17) from Norway who also found that removing the heather from around the plants reduced growth and survival. Heidrich (21) in Germany however, used mulches of Spruce branches 35-40 cm thick and found after 7 years that while all plants showed slightly better height growth only the difference for Oak was significant. The extra cost, nevertheless, is considered to be prohibitive.

Non-organic mulches

The height and spread of Cotoneaster showed a marked increase when the plants were mulched with black plastic film according to Fortney (10) in the USA. Blanke (11) reports similarly from Germany using the mulch on beds of Spruce transplants, while Faulkner (13) records a height growth increase of 20% on Larch and Fir trees in England when a polythene sheet is used as a mulch from sowing until 4 weeks after seedling emergence. Gabriel (19) however, shows that although 1 m square sheets produced good growth on hardwood transplants they all developed multiple stems in the USA.

Vašíček (31) in Czechoslovakia, and Debyle (34) in USA, both recorded improved growth and survival on Pine seedlings using black plastic mulches. Similar results were obtained by Kolster (35) in Holland but he concludes that the use of the plastic is uneconomic. However, Vidali (36) reports promising results from Italy using the mulch in strips 0.4 to 0.5 m wide on Poplar nurseries. He presents comparative data on the diameter growth after two growing seasons that indicate that the mulching increases the growth rate and that it should reduce costs.

Schindler (29) does not recommend the use of plastic foil as a mulch on Spruce transplant beds, but Hermann (22 & 32) markedly increased the survival of Fir and Pine seedlings by mulching with sheets of asphalt interlined paper.

From Israel, Waisel (18) tabulates results to show the advantages, as reflected in survival and branch growth of Eucalyptus, of mulching with 10 and 20 cm of sand. The survival of mulched cuttings and seedlings was respectively 64 and 30% without irrigation, against nil in the controls. Mustafaev (24) in Russia meanwhile used a 2 layered mulch of flat stones to improve the growth of Walnut and Honeylocust trees.

Mixed mulch comparisons

Hunt (20) compared the effects of various kraft and impregnated papers, newspapers and plastic sheets and also sawdust in a Pine plantation in USA. He concludes that, in the conditions of the experiment, any opaque mulch material not less than 60 cm square, that shades out grass and weeds is effective in increasing initial survival. Cultivation alone was ineffective and he further concludes that the increase in survival of mulched plants more than compensated for the extra cost.

Experiments in a Bavarian nursery are quoted by Laber (23) which show that a 3 cm deep peat mulch was not only cheaper than a covering of black polythene film, but also resulted in better development of Norway Spruce seedlings. Mullin (25) compared mulches of silica gravel (3 sizes), hardwood sawdust, vermiculite, shredded sphagnum, mixed silica and sphagnum with rye straw (control) during 3 years on nursery seedbeds of White Spruce in Canada. He found that the sawdust mulch gave the highest germination and survival rate. Although the sawdust treatment produced small and poorly balanced trees, this was believed to be due chiefly to high density in the seedbed and it compared favourably with the rye straw mulch control.

Stephens (28) presents the results of an investigation in USA on yellow Poplar seedlings. The height growth increase in the first growing season using different materials reflected soil temperature differences and was as follows; green polythene 32.5 cm; black polythene 31.0 cm; hay 21.3 cm and bare soil 19.3 cm. Significantly more mulched seedlings (94% vs 79% unmulched) survived the first summer.

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6.5 GRASSES AND CEREALS

Organic mulches

Van Wijk (8) has correlated the yields of maize from plots mulched with oat straw in different parts of the USA. He presents evidence to show that increasing 10 cm soil temperature in the range of 10-27°C increased seedling growth, had little effect in the range of 30-32°C and decreased growth in the range of 32-44°C. Moody (18) shows that significantly higher overall growth and final yields of maize resulted from the use of 7.5 tonnes/ha wheat straw as a mulch as opposed to the same amount being incorporated into the soil. However, Anderson (20) in Canada, states that a straw mulch applied uniformly at 4.5 to 5.6 tonnes/ha to summer fallow immediately after sowing, completely shaded the soil surface and significantly depressed yields of spring and winter wheat.

Olofsson (28) studied the effects of spreading whole or chopped wheat straw at 2 and 4 tonnes/ha on pastures in Sweden over ten years. The treatments increased tiller length in spring and the closeness of the sward. Yields of herbage were increased in some instances. Meanwhile Brengle (39) found that there was no correlation between the yield of spring wheat and a mulch treatment of straw when applied at a rate of 5 tonnes/ha to greenhouse cultures of wheat grown in pots, in water baths at controlled temperature. Van Doren (40) however, shows that on soils of low structural stability showing no deep cracking on drying, a surface cover of straw material improved yields of corn by about 34 kg/ha for each additional 1% of the surface covered. On soils with stable structures, forming large cracks on drying, such surface cover had no effect on yield.

Mulching pasture grasses with 2.5 tonnes/ha hay mulch is shown by Smith (32) to increase the yields of air-dry herbage from 0.6 tonnes/ha (control) to 1.5 tonnes/ha (average for three grasses) in the year of establishment, and from 9.2 to 13.3 tonnes/ha in the following year. Doubling the rate of mulching resulted in a considerable increase in yields during the first year but only slight increases were recorded in the year following establishment.

Moldenhauer (6) discusses a two year experiment involving the growing of six different grasses in a fine sandy loam in tubs in Texas. Mulching with 5 tonnes/ha chopped sorghum increased the number of seedlings under high moisture conditions and caused seedlings to emerge where low moisture had otherwise prevented emergence. He concludes that mulching in Texas would probably have benefited grasses in 31-36% of the years under the prevailing rainfall conditions.

Burrows (15) and Parker (16) show that the practice of mulching the soil with crop residues in USA has been observed to progressively retard the early growth of maize under increasing amounts of mulch, but Taylor (22) records that continuous maize mulched with corn stover yielded more grain than the crop in rotation, in years with below average rainfall.

Several different organic mulches were compared by Wacker (13) in Germany. He found that on five pastures, mulching with compost, farmyard manure or chaff, increased the yields in the following year, advanced the beginning of the grazing in spring by about 6 days and increased the density of the stands. Leaves, potato haulms and straw also increased yields slightly.

Stubble mulching in USA is shown by Power (5) to have given satisfactory yields of spring wheat under favourable weather conditions while Rattray (17) in Rhodesia found that it was advantageous in dry years.

During a seven year experiment, Borst (1) reports that mulching corn with 25 tonnes/ha manure or 5 tonnes/ha wheat straw when the crop was 25-35 cm high, gave significantly higher yields than ploughing in the manure. Yields were highest where mulching followed ploughing. Mulch tillage however, gave slightly lower yields than ploughing in. Peterson (7) also recorded somewhat lower maize yields with mulch tillage and this result is confirmed by Burrows (10).

In an examination of performance over 20 years, Judd (30) concludes that a protective brush mulch was of major importance in establishing and maintaining seedling stands of many range grasses and grasslike plants in Arizona.

Non-organic mulches

Maize was the test crop used by Fritschen (12) to assess the effects of a black plastic surface mulch. Differences observed in the growth of maize from the mulched plots included more rings of brace roots, a less well developed rooting system, a lower maximum height and earlier silking. Dry weight yields were increased by 10% and shelled maize by 8%.

Both clear and black plastic sheets markedly increased the tillering of sorghum in USA, according to Adams (14). Although both increased the yield of grain, the clear plastic tended to give higher yields than the black. In a later paper (33) he compared mulching with petroleum or with a clear plastic film. The initial rate of emergence of sorghum and maize was highest with the plastic mulch, but final stands on both plots were similar. Meanwhile in Hungary, Pusztai (19) found that sorghum yields were increased by up to 46% under white plastic, 68% under black and 76% under a transparent mulch.

Zakharov (23) claims that in Russian experiments, he found that mulching with transparent film trebled the yield of maize and doubled the yield of cotton. A black mulch was found to have little effect on yields. Similarly, Hopen (27) reports from USA, that maize grown in soil mulched with a transparent film had a faster rate of growth and produced earlier and greater yields than maize grown in unmulched soil, while maize mulched with a black film was intermediate in growth rate, earliness and total yield. Pendleton (31) meanwhile, found that yield increases of maize were greater from early - than late - covering and from white - thanblack covering. Translucent plastic sheeting, installed over the row just after emergence, resulted in increases of grain yield of up to 30% during a 3 year study in USA according to Free (24).

Harpaz (25) shows that a synthetic rubber, pre-emergence spray which formed a temporary mulch to aid grass establishment on sand dunes in Israel, had no detrimental effect on the emergence or growth rate of the plants. Griffin (29) reports from USA that a total or partial soil cover of plastic film, or a partial cover of asphalt or asphalt coated paper gave exceptionally good yields of grain sorghum.

Mulching the seeded rows of sweet corn with a film of asphalt emulsion or with a layer of water in polythene bags is shown by Miller (38) to hasten plant development but not to significantly affect yields. In other American trials (36) however, the yields of sweet corn are shown to be about 7 tonnes/ha on water-bag-mulched plots, compared with 6 tonnes/ha on plots mulched with clear plastic only and 4 tonnes/ha on unmulched plots.

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6.6 TROPICAL AND SUB-TROPICAL CROPS

Organic mulches

Trash mulching with residues left after cutting burnt cane crops, combined with moderate fertilizing, is shown by Blundell (1) to increase average yields of ratoons from 70 to 100 tonnes/ha on red volcanic soils. Mather (11) in India and Gill (29) in Pakistan both found significantly increased yields of sugar cane when using a trash mulch. Experiments in Taiwan are reported by Chang (21), Tang (25) and Lee (42). Chang used trash at 15-20 tonnes/ha and found that mulching increased the yield by 3-7% in the plant crop and the ratoon. Tang increased cane and sugar yields with bagasse or trash, while Lee applied bagasse furnace ash at a thickness of 5-16 cm to increase yields by 11-28% in plant cane and more in successive ratoons. Stalk growth and root development were significantly improved. Thompson (46 & 57) reports from South Africa that trash mulching instead of burning, increased the annual yield by 10 tonnes of cane and 1.2 tonnes of sucrose per hectare.

Bull (26) and Robinson (36) report from Tanganyika on the use of trash mulches with coffee. Bull shows that the downward growth of tap roots and the development of the root system as a whole was increased, while Robinson found that a single annual application at 18 kg per tree significantly increased yield and was as effective as 36 kg applied at the same time (after the long rains), or as 18 kg applied after both rainy seasons. Pereira (3) in Kenya, quotes field trials with large yield increases when a mulch was applied to coffee before the rains, and these results are confirmed (19) where mulching before the long rains is shown to produce increased clean coffee yields by as much as 0.5 tonnes/ha and post-rain mulching by 0.3 tonnes/ha.

Awatramani (40) in India found that a mulch of dry leaves at 7.5 tonnes/ha had a negligible effect on coffee yields, but a mulch of fruit skin from the pulper at the same rate yielded a significant increase, while Vaz (18) reports from Angola that mulching with 8-10 cm dried grass between alternate rows of coffee increased yields by 172% as against 233% from mulching between all the rows. Alférez (47) in El Salvador shows that for five years, grass mulches significantly increased the mean yields of coffee and stimulated the growth of trees while Schindler (37) from New Guinea, claims that yield increases due to mulching more than compensated for the extra costs involved.

Maliphant (16) shows that grass mulches in Trinidad gave greater yields of cocoa than those given by equivalent amounts of chemical fertilizer but at a greater cost, while Jordan (52) quotes the following yields from 2-3 year old cacao plants - natural regeneration plots - 330 kg/ha, leguminous cover plots - 725 to 900 kg/ha and mulched plots - 1200 kg/ha.

A 25 cm layer of hay, applied to 3 weeks old soya is shown by Orbea (4) in Argentina to have more than doubled the green weight at 4 months in 8 varieties, and to have increased it by over 50% in 2 other varieties. Lawes (14 & 15) meanwhile, demonstrates that by applying surface mulches or vertical mulches (in which a 25 cm slit is drawn in the furrow and filled) of groundnut shells, that the seed cotton yield in Nigeria is increased by more than 20% over normal tied ridge cultivation.

Tobacco leaf yields in USA, are shown by Batchelder (48) to be significantly increased by a straw mulch during the first two seasons. The results indicate that improved soil moisture is a primary factor affecting tobacco growth and yield on exposed subsoils.

Oil palm growth in soil mulched with vine stalks or with straw is greater than in bare irrigated soil according to Wormer (8) and similar results are given by Uribe (38) using a mulch of sawdust or rice-hull either widespread, or placed around individual palms in the plantation, to a radius of 1 to 1.5 m.

Munro (12) reports that the application of a heavy straw mulch to groundnuts resulted in yield increases of 7% from tie ridged plots and to more than 200% from flat plots. Yield increases of 50% are claimed by Prevot (24) using a heavy mulch of husks while Ashrif (39) shows that the application of a grass mulch at about 6 tonnes/ha four weeks after germination of groundnuts also increased the yields in three consecutive years.

Mulching pineapples with rice straw is shown by Su (9) to have increased the growth and yield, leaf nutrient contents, fruiting percentage, sucker formation and also the percentage of sound pineapples in Taiwan.

In Australia, Cockroft (51) and Morris (53) both used a straw mulch with peach trees to obtain the most growth and the heaviest crops in soil management trials. Yield increases of 146% over 5 years are listed by Cockroft.

Iosava (69) presents the results of mulching with peat in a tea plantation in Russia. The average yields over 6 years with a standard fertilizer treatment, showed increases of 76% with a mulch at 50 tonnes/ha and of 87% when the mulch application was at twice that rate. Meanwhile in China, Shyu (71) shows that on terraced and non-terraced plots, the use of a rice straw mulch at the rate of 20 tonnes/ha benefited tea growth and gave the highest yields of fresh leaf from 4 year old bushes.

Mandarin seedlings were mulched with forest leaves, with or without manuring in South India, by Kannan (31) who presents results to show that both treatments showed better vegetative growth, withstood drought better and also gave the highest yields. They also produced earlier flowering and harvesting than in the control and cover cropped trees.

Non-organic mulches

Milner (33) quotes test results from Arizona to show that an emulsion of petroleum resins sprayed as a mulch 12 days after sowing cotton resulted in an increase in yield of 34%. Phillips (44) however, found that an increase in yield of cotton only resulted when a petroleum mulch was applied to a silt loam. He also found that application at an early date of planting (April 16) significantly increased the rate of seedling emergence. Ranney (63) meanwhile, reports that cotton seedling emergence was consistently increased by a black petroleum resin, and that it was maximum when the mulch was applied in 15 cm bands. Russian work by Abdurakhimov (65) however, suggests that a pre-emergence oil-mulch increased seed cotton yields to various extents, depending on the date of sowing and on whether the oil mulch was applied in strips or to the whole soil.

Other Russian work by Devočkin (28) and Jazykov (30) shows that an impregnated paper mulch sometimes covered by a 4-5 cm layer of soil, contributed to a higher percentage germination and thicker stands of cotton, while Bennett (49) used a black plastic mulch to accelerate early cotton growth and fruiting of the plants. Emergence was advanced by 7-10 days, maturity by 2 weeks and yields increased by up to 1 tonne/ha

Newman (54) describes how a tobacco seedbed in USA was covered with a film of clear plastic over which the usual cheese cloth was placed. The film was removed when the plants reached the 5 leaf stage. Emergence was 3 days earlier and plant density 27% higher than in the controls without the plastic mulch. Italian work on the effects of different coloured plastic mulches is given by Vardabasso (58). No differences in germination of tobacco were noted under the different colours but red or yellow plastic sheets appeared to be more favourable to growth than blue, green or white ones.

Chouteau (50 & 66) shows that plastic mulching promoted rapid growth and early maturity but had little effect on the yield or on the filling capacity of cut tobacco. Advancing the harvest date by 15 days decreased yield by 12% on mulched plots which were irrigated and by 20% on those which were not.

The effect of mulching pepers has been observed by Downes (10) who found that the application of polythene strips tended to promote early vegetative development rather than early fruiting, and to increase total yields. Material covered with aluminium produced plants of lighter colour than those mulched with black polythene. Jakrlová (61) reports that mulched peppers developed their generative organs earlier and produced significantly more buds, flowers and fruits and he therefore assumes that mulching with polythene will increase both yield and earliness in peppers - while Gerard (60) shows that some petroleum resin emulsion treatments produced a favourable environment for the germination of fall bell peppers, and that the yields were more than 5 times the yield obtained from multi irrigated bare soil treatments.

Murata (62) describes how the application of a white expanded-polystyrene board mulch, 25 days before the heading of rice plants increased grain yield by about 10-15% in plots sown at the normal time or later.

Increases in the yield of pineapples are claimed by Py (55) and Ekern (59) both of whom used a black polythene mulch and a similar material was used by Garcia (67) to obtain increases in the plant size of bananas.

Panje (35) compared the effects of black and translucent polythene mulches on a sugarcane crop. The most rapid germination and most vigorous shoots were produced under the translucent film, viz 37% after 62 days, compared with 83 and 100 days for black film and the control respectively.

Cahoon (20 & 27) obtained significant growth increases on citrus seedlings and budlings near the coast in California using various types and colours of polythene or vinyl plastic sheets. Further inland growth increases were found on sweet orange only. Sood (56) however, shows that the use of a black polythene mulch for 3 years on a 7 year old Italian lemon tree produced roots in the top 15 cm of soil whereas the control had none. The control plant had longer roots, more secondary and considerably fewer fibrous roots.

Sisal nursery plants in Angola, covered with a black plastic mulch are shown by Hongler (41) to develop more vigorously and to have a healthier leaf colour than the control plants. Similar results are quoted by Hopkinson (68) in Tanzania.

Mixed mulch comparisons

Mulching tobacco seedbeds with fine grass, hay, chopped thatching grass or coarse sand, all gave good results in Rhodesia, according to Garmany (5). He found that grass lengths of 15-20 cm were better than shorter lengths which tended to pack. Meanwhile, Engle (22) found over 3 years that a paper mulch reduced both the yield and quality of tobacco in USA whereas a straw mulch reduced yield but improved quality. Black polythene mulches advanced harvesting by 10 days but had little effect on yield or quality. In no case did he find mulching to be economic.

In Italian experiments with cotton, Sarno (64 & 70) claims that mulching with black, white or clear plastic sheets between the rows, was better than mulching with straw or with no mulching. It is concluded that clear plastic sheets are best, since they gave the highest yields, having produced almost 100% germination.

Mendoza (17) gives the results of an experiment over two years in the Philippines with coffee. Plots mulched with coconut, Imperata grass and banana leaves increased yields by 63%, 66% and 190% respectively. A covering of black plastic did not appreciably increase the yield and the trees showed early yellowing of the leaves and branch die-back. Moreover the plastic was pierced by Imperata grass. In Kenya, Blore (34) shows that mulching coffee with either a petroleum emulsion or Napier grass had no significant effect on the establishment of seedlings in the field.

Lee (32) found that the increase in yield of sugarcane in Taiwan due to mulching, was proportional to the compactness of the soil. Cane trash was considered to be the most practicable material, since a sand mulch was good only on heavy clay soil. Panje (43) meanwhile, increased cane yields over 5 years in India using both black polythene and chopped trash. The latter was recommended since it was cheaper, although the yields were not so large.

Six methods of soil management were compared by Gvazava (6) on young orange trees in Russia. The results show that tap and root growth was most vigorous and fruit set was best under a mulch of organic material throughout the year and also under a black paper mulch until August followed by annual grasses. Growth was least satisfactory under a perennial grass-legume cover crop.

Black polythene was considered to be superior to straw as a mulch for pineapples in Guinea according to Py (45). Straw depressed vegetative growth whereas polythene had favourable if not significant effects on growth and yield.

The effects of various types of paper, plastic and natural organic mulches were studied by Lange (13) in Hawaii. The best growth and highest yield of papaya were obtained with mulches made of polythene or with a polythene lamination. Chopped branches also increased yields significantly, but fresh bagasse was less satisfactory.

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Any comments or suggestions on this paper should be sent to the author.

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